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Analysis of earthquake catalogue for seismic hazard analysis of Warangal city

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ABSTRACT

Seismic hazard analysis involves the quantitative estimation of ground shaking hazards at particular site. The composite catalogue of the study area spanning from 1800 to 2014 A. D. (214 years) has been used for evaluating the seismicity of the Warangal region within 350 km radial distance with NIT Warangal (17.98°N Latitude and 79.53°E Longitude) as center with a total of 339 earthquake events. About 36% of the events with reported magnitude M_w > 3.0 in the catalogue are identified as foreshocks and aftershocks and subsequently removed by applying the dynamic window algorithm developed by Gardner and Knopoff (1974) and modified by Urhammer (1986), and finally a new catalogue of 248 earthquake data was prepared. A graphical procedure known as the Visual Cumulative (CUVI) method formulated by Mulargia and Tinti (1985) and the statistical approach suggested by Stepp (1972) are used in the present study to estimate the period of completeness of the catalogue. The uniform hazard spectra (UHS) for different reference return periods (*T* = 72, 475, 975 and 2,475 years) for rock/stiff site conditions have been computed and compared with Design Basis Earthquake (DBE) of the BIS (IS 1983:2002).

Keywords: Earthquake Catalogue, Seismic Hazard Analysis, Disaster Management, Warangal

1. INTRODUCTION

Earthquakes are one of the most devastating among the various natural hazards. The hazards associated with earthquakes are referred as seismic hazards. India has experienced a number of the world's greatest earthquakes in the last century. In fact, more than 50% area in the country is considered prone to damaging earthquakes (Anbazhagan and Sitharam, 2008, Chandra 1977, Cramer and Kumar, 2003, Kalyan et. al., 2009Sharma et. al., 2004). The north eastern region of the country as well as the entire Himalayan belt is susceptible to great earthquakes of magnitude more than 8.0. Indian earthquakes have shown some remarkable features which have implications on strategies for reducing earthquake disasters in the country. Non-structural damage to a few buildings in New Delhi caused by the M_s = 6.6 Chamoli earthquake of 1999 with an epicentral distance of 280 km reveals this possibility. The 700-km long seismic gap (*central gap*) between the rupture zones of two great earthquakes, the 1905 Kangra earthquake (M = 8.6) and the 1934 Bihar earthquake (M = 8.4), is considered to be a potential area for a great earthquake.

The seismic hazard or the potential of a site to experience ground motion due to an earthquake cannot be altered. The risk faced by human habitat due to earthquakes can be reduced by making man made systems and structures less vulnerable and more robust to withstand the ground motion. Seismic risk has a character to increase with time if continuous mitigating actions are not taken.

This paper outlines the analysis of basic earthquake catalogue for Warangal city which would be very useful for the further seismic hazard study of the region. Tools like MS Excel, ArcGIS and MATLAB has been extensively used for the analysis.

2. METHODOLOGIES

Earthquake catalogues provide the detailed insight into the seismicity of a region required to develop seismogenic zoning scenarios, in conjunction with seismotectonic and geological information for probabilistic approaches based on classical Cornell-McGuire theory.

2.1. Geographical Extent of the Study Area and Geographical Coordinate of the Site

The earthquake catalogue compiled for the current project covers historical and instrumental seismic events in a circular area of 350 km radius, with NIT Warangal at its center. The geographical co-ordinates of NIT Warangal are 17.98°N Latitude and 79.53°E Longitude. A total of 339 earthquakes (wheeler and muller, 2001. Rao and Rao, 1984) with moment magnitude (M_w) greater than 3 have been identified from different sources in this geographical area. This catalogue spreads over a period of 214 years from 1800-2014 A.D.

2.2. Homogenizing Earthquake Magnitude Definitions

A complete earthquake catalogue with a uniform magnitude scale for expressing the size of past earthquakes is a prerequisite for a reliable parameterization of the distribution used in a hazard analysis. The relationships as written (Kramer, 1996) in equations (1-4) have been used to convert the body wave magnitude (M_b), local magnitude (M_L), and surface wave magnitude (M_s) to the moment magnitude (M_w).

$$M_w = 0.667\log[M_o] - 10.7 \quad (1)$$

$$\log[M_o] = 24.66 - 1.083(M_s) + 0.192(M_s^2) \quad (2)$$

$$\log[M_o] = 18.28 + 0.679(M_b) + 0.077(M_b^2) \quad (3)$$

$$\log[M_o] = 18.31 + 1.017(M_L) \quad (4)$$

Where M_o is the seismic moment in dyne-cm.

2.3. Declustering Process

Declustering is the process removal of dependent earthquake events (foreshocks and aftershocks) from an earthquake catalogue (van et. al., 2012). The Poissonian assumption of earthquake recurrence implies that the earthquake event occurs randomly with no memory of time, size, or location of any preceding event.

2.3.1. Static Window Method

The declustering approach by the static window method is based on the removal of foreshocks and aftershocks which fall within a constant time and distance window. Based on regional characteristics of the seismicity the temporal and spatial windows are chosen

in the current study, a uniform time window of 90 days (from the time of occurrence of the main shock) and a uniform spatial window of 30 km (distance from the main shock) have been adopted.

2.3.2. Dynamic Window Method

The dynamic window method developed by Gardner and Knopoff (1974) and modified by Urhammer (1986) illustrates declustering process of removal of dependent earthquake events (foreshocks and aftershocks) from an earthquake catalogue. Earthquake events are random and memory-less, therefore foreshocks and aftershocks be removed from the earthquake catalogue. The temporal and spatial window parameters would, in this case, be different, based on the magnitude of main events.

2.4. Estimation of Completeness Periods

Another important step in processing an earthquake catalogue to make it suitable for a probabilistic seismic hazard analysis is the definition of the time window in which the catalogue is presumed to be complete. Catalogue incompleteness exists because, for historical earthquakes the recorded seismicity differs from the "true" seismicity.

2.4.1. Visual Cumulative/CUVI Method

In the CUVI method, the period of completeness for a given class is considered to begin from the earliest time when the slope of the fitting curve can be approximated by a straight line. Earthquake events are divided into different magnitude classes, as incompleteness is known to be a function of magnitude. Either the subdivisions could be intervals (for instance ▪*M* = 0.5) or cumulative, containing all the events of magnitude exceeding the lower bound of chosen interval. The catalogue is considered to be complete from the time when the trend of the data stabilizes to approximate a straight line. The completeness interval is the number of years from the beginning of the period to the last year of occurrence in the catalogue.

2.4.2. Stepp's Method

The entire earthquake catalogue is grouped into magnitude ranges of say ▪*M* = 0.5, in time interval of 10 years. The average number of events per year, *R(M)*, are evaluated for each magnitude class for increasing time interval lengths, starting with the most recent time interval. The first window consists of the most recent (e.g., 10 years), the next window would consist of the recent 20 years, and so on. An analysis of the series of *R(M)* obtained as above will show the length of time window for which *R(M)* becomes stationary for a given magnitude range. Stepp (1972) modeled *R(M)* as a Poisson point process in time, such that, for a time interval of *T* years, the variance of *R(M)* is given by equation (5).

$$S_R^2 = \frac{R\,(M)}{T} \qquad (5)$$

The S_R is the standard deviation of the mean rate *R(M)*.

2.5. Gutenberg-Richter Frequency-Magnitude Recurrence Relationship

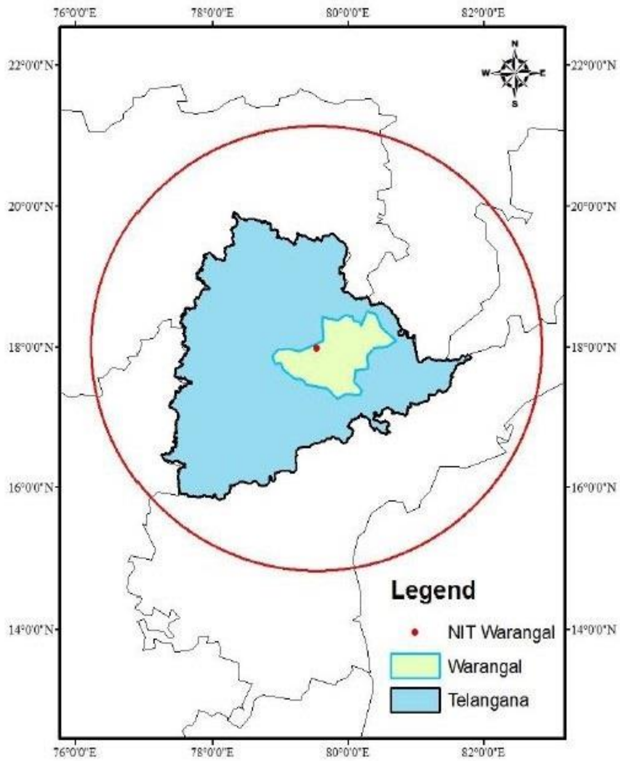
The yearly occurrence rate of earthquakes with magnitude greater than or equal to *M* in a given region can be described by Gutenberg-Richter (Eq. 6) recurrence relationship (Gutenberg and Richter, 1954)

$$\log_{10}(\lambda_M) = a - bM \qquad (6)$$

Where λ_M is the mean annual rate of exceedance of magnitude M, *a* and *b* are the model constants specific to the source zone. The 10^a is mean yearly number of earthquakes of magnitude greater than or equal to zero and b describes the relative likelihood of large and small earthquakes. The *b*- value is greater than one denotes a situation where the number of large events is relatively small compared to those of small magnitudes.

3. RESULTS

The study area selected for the present study is a circular area of 350 km radius, with NIT Warangal at its center as shown in fig. 1 and faults and lineaments in the study area are digitized to identify possible sources of future earthquakes in the region as shown in fig. 2.



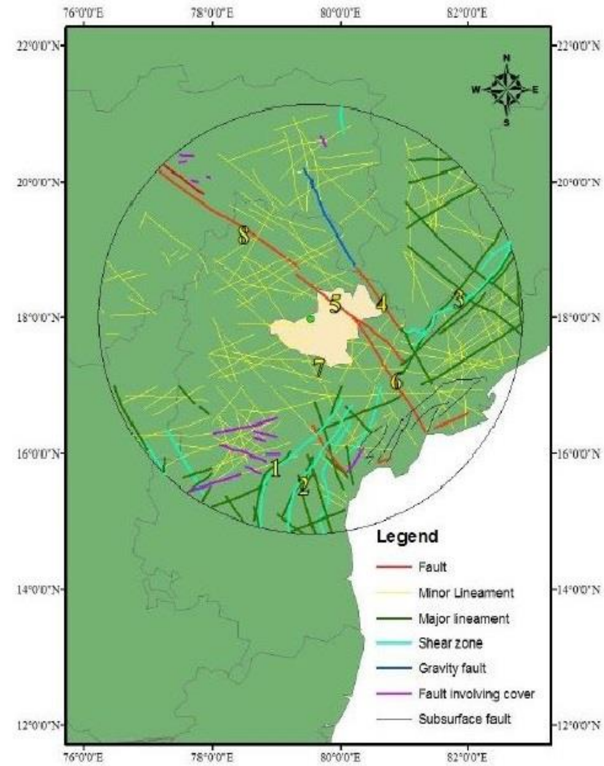
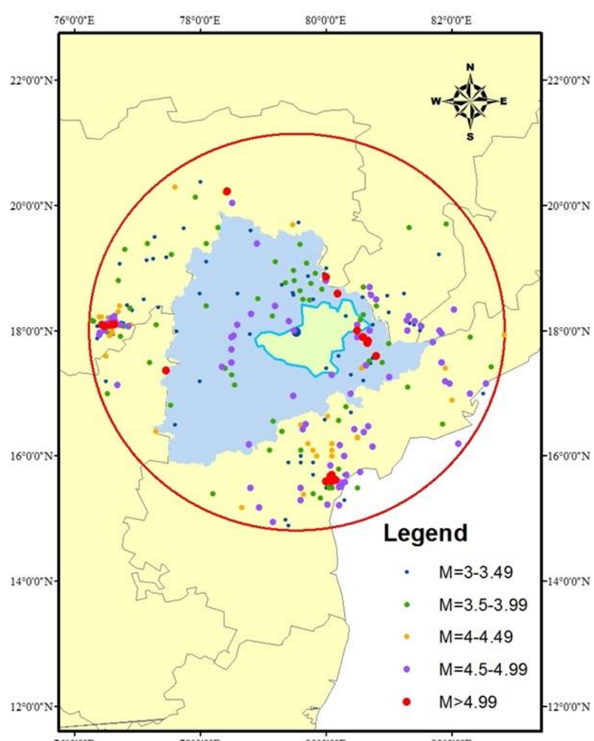


Figure 1 Geographical extent of the study area **Figure 2** Digitized faults and lineaments in the study area



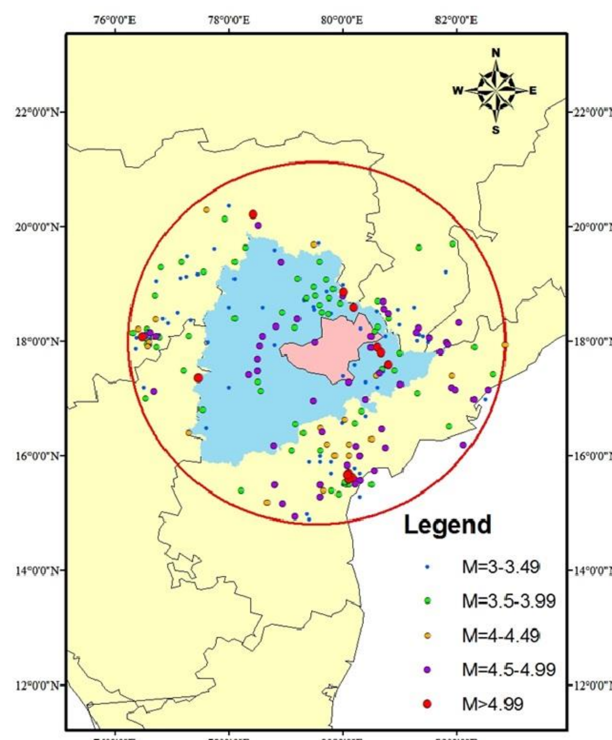


Figure 3 Seismicity of study area before declustering **Figure 4** Seismicity of study area after declustering

The declustering process is carried out by using static and dynamic window methods. Since the two declustering algorithms described above, produced essentially comparable results, dynamic window method developed by Gardner and Knopoff (1974) and modified by Urhammer (1986) has been used in this study as shown in fig. 3 and fig. 4.

Completeness interval and exceedance rates computed by using CUVI method for the Warangal region considering single seismic zone are shown in Table 1 and 2 respectively:

Table 1 Completeness Interval for the Warangal region from CUVI and STEPP'S method

Magnitude classes (M_w)	CUVI Method		Stepp's Method	
	Completeness period	*Interval (years)*	*Completeness period*	*Interval (years)*
3-3.49	1984-2014	30	1974-2014	40
3.5-3.99	1990-2014	24	1974-2014	40
4-4.49	1986-2014	28	1954-2014	60
4.5-4.99	1984-2014	30	1954-2014	60
>5	1800-2014	14	1800-2014	214

Table 2 Parameters for recurrence relationship for single source zone

Period (Years)	Interval (Years)	Magnitude Range	M	Number of Events After Completeness	Annual Rate	Cumulative Annual Rate	Log(λ_m)
1968-2014	46	3-3.49	3.25	78	1.695652	4.1630559	0.619412
1963-2014	51	3.5-3.99	3.75	58	1.137255	2.4674037	0.39224
1958-2014	54	4-4.49	4.25	22	0.407407	1.3301488	0.1239
1954-2014	60	4.5-4.99	4.75	52	0.866667	0.9227414	-0.03492
1800-2014	214	>5	5.5	12	0.056075	0.0560748	-1.25123

Gutenberg-Richter's *a* and *b*-values are calculated for the study area and shown in Table 3. These values can be further used for modelling of the seismicity and evaluation of the seismic hazard.

Table 3 Seismicity parameters from CUVI and Stepp's method

No.	Method	Number of Events	*a*	*B*	M_{min}	λ_M	$\beta = 2.303\, b$
1	CUVI	222	3.338	0.783	3	9.75	1.80
2	Stepp's	217	3.438	0.803	3	10.69	1.85

Uniform Hazard Spectrum corresponding to 475 years return period shown in fig. 5. The figure also shows the response spectra as given in IS 1893 (Part 1) 2002 for rock site, where DBE stands for Design Basis Earthquake.

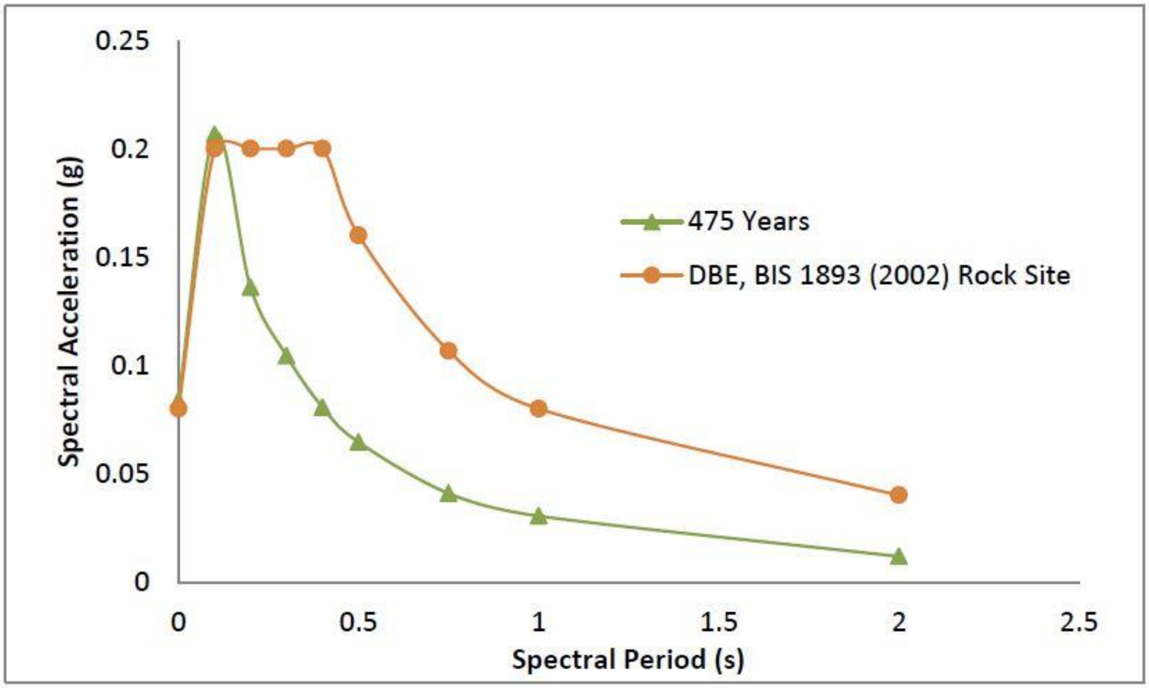


Figure 5 UHS for 475 Return Period (Expected and IS code Value)

4. CONCLUSIONS

The study presented in the paper was to define seismic input for Seismic Hazard Analysis of Warangal City. Seismicity of the study area is controlled by weak to moderate earthquakes with sources located at fairly large distances from the region. Few moderate earthquakes (M>5) in the recent years, signifies the need for detailed Seismic Hazard Analysis of the region.Based on the results presented in this study, the following conclusions are drawn:

1. For the Warangal, the estimated values of *a* and *b* are 3.34 and 0.783 respectively, which are the important input parameters of the Gutenberg-Richter recurrence relationship.
2. The bounded Gutenberg-Richter recurrence relationship is found to give an acceptable ground shaking hazard for Warangal.

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